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NRL REPORT 3864

NRL-FR-3864

# AN AIRPLANE APPROACH-SPEED INDICATOR

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NAVAL RESEARCH LABORATORY

WASHINGTON, D.C.



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NRL REPORT 3864

# AN AIRPLANE APPROACH-SPEED INDICATOR

C. R. Grant and E. F. McClain

August 22, 1951

Approved by:

John P. Hagen, Head, R. F. Research Branch
John M. Miller, Superintendent, Radio Division I

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## *ABSTRACT*

*An airplane approach-speed indicator has been developed at the Laboratory to measure the air speed of jet planes in the final stages of carrier landings. A cw Doppler radar was used to measure the relative velocity of the aircraft with respect to the carrier. The velocity of the wind across the deck was added to the closure velocity, thereby obtaining the true air speed of the landing aircraft. An indicator mounted on the port catwalk presents the information to the landing signal officer.*

## *PROBLEM STATUS*

*This is a final report on the problem; unless otherwise notified by the Bureau, the Laboratory will consider the problem closed one month from the mailing date of this report.*

## *AUTHORIZATION*

*NRL Problem R04-48D*
*RDB NA710-070*
*BuAer Problem TED-NRL-SI-202*

*NOTE*

*Attention is directed to the section of this report dealing with the installation on board the USS TARAWA. This report contains information based on tests made currently with and subsequent to those reported in U.S. Naval Air Test Center Report No. EL 9128, ET331-064, "Final Report on Providing Assistance to NRL and ComAirLant in Operational Evaluation of LSO Approach Speed Indicator," 20 June 1951, Project TED No. PTR EL 9128. It was found that the range measurements reported in the NATC report were based on operation with a faulty transmitter for which NATC was not responsible.*

*Manuscript submitted for publication July 12, 1951*

# AN AIRPLANE APPROACH-SPEED INDICATOR

## INTRODUCTION

A reliable indication of aircraft speed in the final stages of carrier landings is needed by the landing signal officer, especially when jet planes are landed at night. A cw Doppler radar, developed at the Laboratory, presents the required information.

## THEORY OF OPERATION

The approach-speed indicator, based on a relatively uncommon type of radar system, uses the Doppler effect to measure the velocity of a moving target relative to the radar antenna system. If electromagnetic energy from a radar transmitter is reflected from a moving target back to the receiver, the frequency of the returned wave will differ from the frequency of the transmitted wave. This difference in frequency will be directly proportional to the relative velocity between the radar system and the moving target. Relative velocity here actually means a change in target range and not a change in azimuth. That is, a target must be changing range to cause a frequency shift, and a target that moves in a perfect circle with the radar as a center will not cause a shift. The magnitude of the Doppler shift or the change in frequency is given by

$$\Delta f = \frac{2\,v\,f}{c}\ ,$$

where

$\Delta f$ = the difference in frequency between the transmitted and reflected signals in cps,

$v$ = velocity of the target with respect to the radar in knots,

$f$ = the transmitted frequency in cps, and

$c$ = the velocity of light in knots.

The value of c is constant and equal to 161,900 knots; for this equipment, f has a fixed value of $1.01 \times 10^{10}$ cps. Therefore, for every knot of relative velocity between the radar and target, the received signal will differ in frequency from the transmitted signal by 34.66 cps. For example, if the target is an aircraft traveling at a speed of 100 knots relative to the antenna, the difference frequency would be 3,466 cps.

The antennas and radar of this equipment are designed to be mounted under the ramp at the after end of the flight deck and are so oriented that an aircraft following a normal approach pattern (Figure 1) will be acquired by the radar about 500 yards astern. Since the aircraft has has not completely finished its turn and hence is not flying directly toward the radar at this

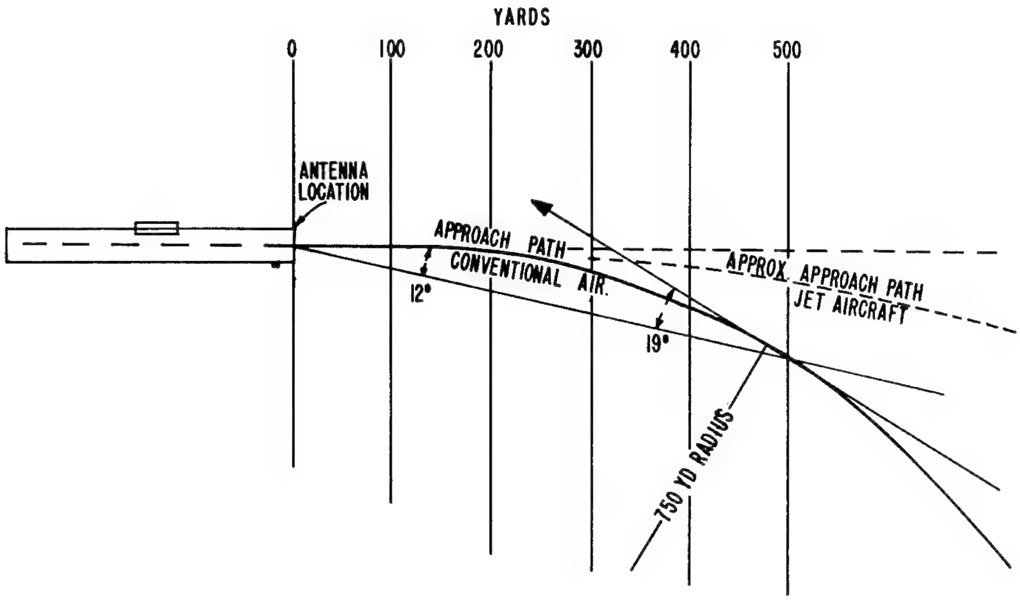



*Figure 1 - Assumed approach path of landing aircraft*

point, the indicated velocity will be about 5 percent low. As the aircraft straightens out in its final approach, the reading becomes quite accurate.

The difference or Doppler frequency from the radar is measured by a frequency sensitive circuit and displayed on a meter calibrated in knots. This meter is contained in an indicator unit at the landing signal officer's position. Since the air speed of the approaching plane is desired, provisions are made for adding the wind speed over the deck to the relative speed between the aircraft and the carrier as measured by the radar. The wind speed is set in manually by a control on the indicator.

## DESCRIPTION OF APPARATUS

The prototype approach-speed indicator, developed from a study of this problem, includes the radar unit, power supply unit, and indicator unit.

The radar unit (Figures 2, 3, 4, 5, and 6) contains the complete r-f system including antennas and antenna feeds, klystron transmitter, balanced mixer, directional coupler, and waveguide attenuator. It also contains the audio amplifiers, audio attenuator, and filters.

The radar unit, contained in a waterproof aluminum housing, is suspended from the ramp on the stern of the aircraft carrier. The mounting mechanism provides for adjustment of the elevation angle of the housing to $\pm$ 22.5$^{o}$ from the horizontal and $\pm$ 15$^{o}$ in azimuth. Since the antennas and antenna feeds are rigidly mounted to the housing, this adjustment enables the antennas to be oriented properly with the beam along the prescribed landing path.

Access to the radar unit is made by opening the rear cover, held in position by eight swing bolts (Figure 5). The audio amplifiers and controls are mounted on a hinged panel, which can be tipped forward to make the r-f system and klystron accessible (Figure 6).

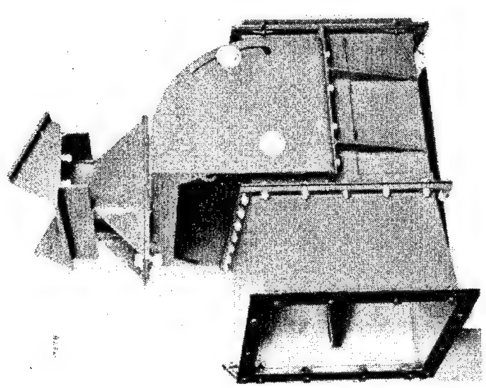


*Figure 2 - Radar unit, side view*

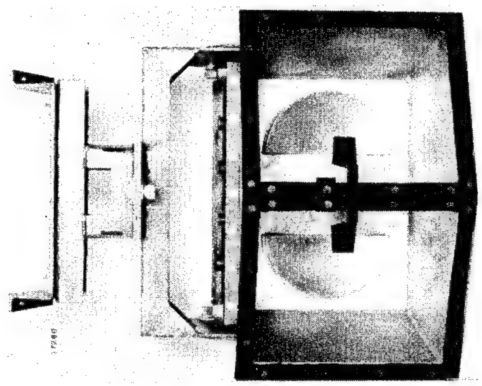


*Figure 3 - Radar unit, front view*

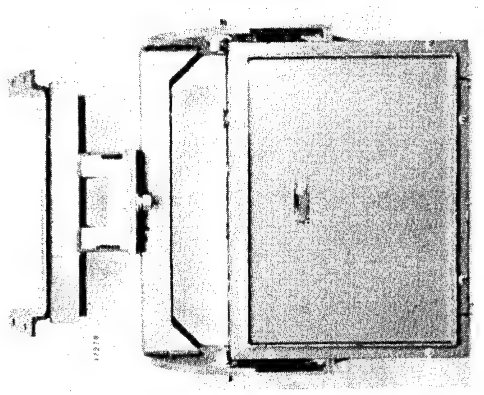


*Figure 4 - Radar unit, rear view*

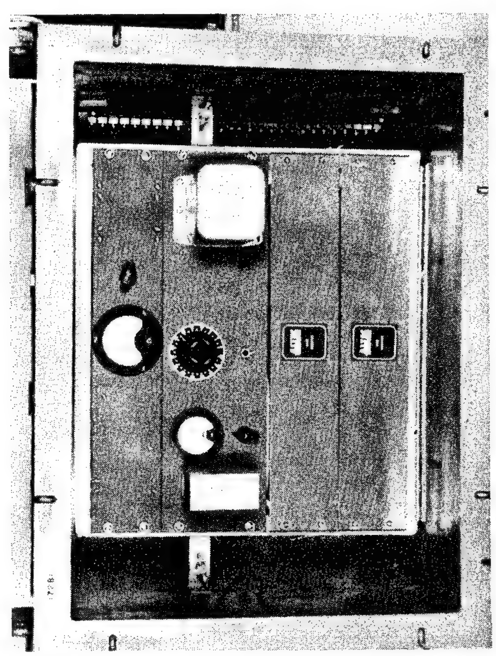


*Figure 5 - Radar unit, rear cover removed*

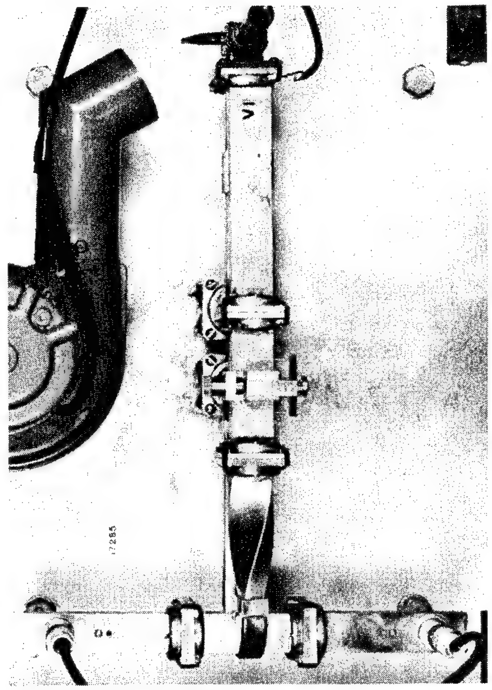


*Figure 6 - Radar unit, rear cover removed and control panel lowered to show plumbing*

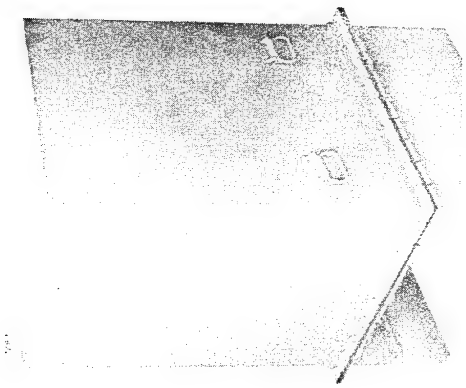


Figure 7 - Power supply unit

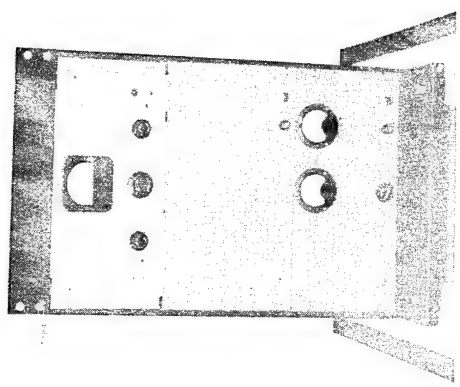


Figure 8 - Power supply unit, cover removed, front view

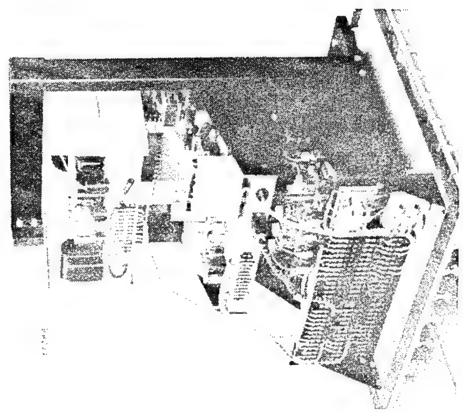


Figure 9 - Power supply unit, cover removed, side view

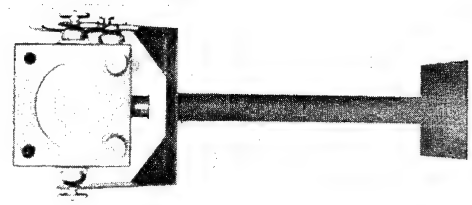


Figure 10 - Indicator unit, showing mounting pedestal

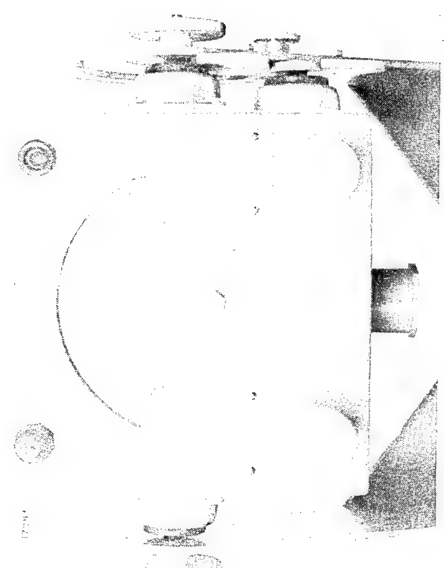


Figure 11 - Close-up of indicator unit

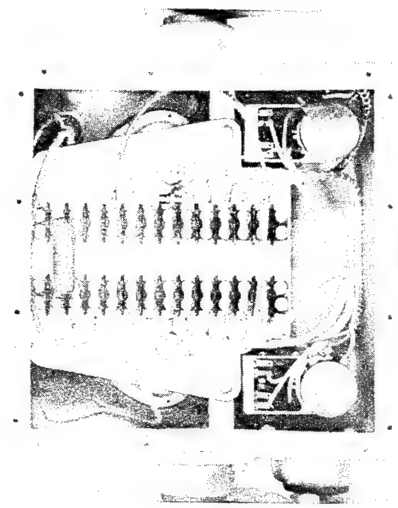


Figure 12 - Indicator unit, rear view with cover removed

The power supply unit housing (Figures 7, 8, and 9) contains the following equipment mounted on a standard relay rack, which has been shock mounted:

(a) klystron anode power supply
(b) klystron heater supply
(c) calibration oscillator
(d) power supply for calibration oscillator and audio amplifiers
(e) wind-set power supply
(f) frequency meter and associated power supply
(g) power-alarm-relay power supply.

The power supply unit, designed for deck mounting, is housed in a watertight enclosure of steel and aluminum. A one-piece watertight cover, held in place by swing bolts, gives ready access to the equipment.

The indicator unit (Figures 10, 11, and 12) contains the speed indicating meter, main power switch, wind-set control, calibration control, and alarm lamp. After preliminary adjustments, all operations are controlled from the indicator. A plug on the front of this unit provides access to the zero adjustment on the speed indicating meter.

The indicator unit is waterproofed and shock-mounted to a pedestal designed for deck mounting and is adjustable in height. The front of the unit is adjustable from a horizontal position to within a few degrees of vertical.

## ELECTRICAL DESCRIPTION

A block diagram of the equipment is shown in Figure 13 and a complete wiring diagram in Figure 14.

### Signal Channel

The audio frequency signal from the balanced mixer is fed through a repeat coil and then through the normally closed contacts of "calibrate relay" number 1 to the input transformer of an Altec-Lansing A-420 audio amplifier. The output of this amplifier, which provides two stages of amplification (V2 and V3), is fed through a 1400-cycle high-pass filter and a 0 to 60-db step attenuator to the input of another Altec-Lansing A-420 audio amplifier (stages V4 and V5). The output of the second audio amplifier is fed through a 5000-cycle low-pass filter, whose output is, in turn, fed through an interconnecting cable from the radar unit to the power supply unit. A phone jack is provided in the radar unit for monitoring the audio signal at the output

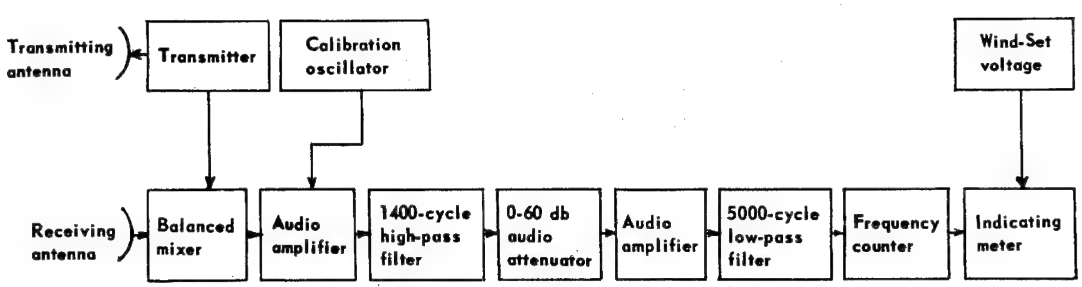



*Figure 13 - Block diagram of system*

of the 5000-cycle low-pass filter. In the power supply unit, the audio signal is fed through the normally closed contacts of the wind-set relay to the input of a Hewlett-Packard frequency meter.

The frequency meter circuits operate in the following manner: stages V16, V17, and V18 are a resistance-coupled voltage amplifier used to provide the desired sensitivity. The two 6V6 tubes, V19 and V20, are driven by voltages taken from the plates of V17, and V18, respectively. The voltage is a square wave because of intentional overloading in the voltage amplifiers. Tubes V19 and V20 are connected as triodes and are used to switch a constant current to alternate load resistors. A dc regulator, V24, is used to make the current applied to the load resistors independent of the characteristics of the switching tubes and the voltage applied to them. The grid and screen-grid voltages on V24 are obtained from a gas-tube voltage regulator V25, a VR150. Considerable degeneration is used in the cathode, thus making the plate current practically independent of plate or filament voltages or tube constants. The imperfect regulation of the VR tube is compensated by feeding a small amount of current from the high voltage dc source to the cathode of the current regulator tube V24. At each half cycle of the input voltage, the regulated current is switched from one load resistor to the other, and a current pulse is sent through the speed indicating meter because of the change in charge on the pair of condensers connected to the 6H6 tubes, V21 and V22. The current pulses are rectified by a diode bridge rectifier, and their average value is measured by the speed indicating meter, a dc milliammeter. The reading is proportional to the number of pulses per second and therefore proportional to the signal frequency, which is a function of the speed of the landing aircraft. Thermal emission current in the diode rectifiers is suppressed by applying a small positive voltage to the cathodes of the diodes. This voltage is obtained from the drop across the 82-ohm fixed resistor in series with the VR tube V25. The speed indicating meter is connected in parallel with the 3900-ohm resistor in the plate circuit of diodes V21 and V22.

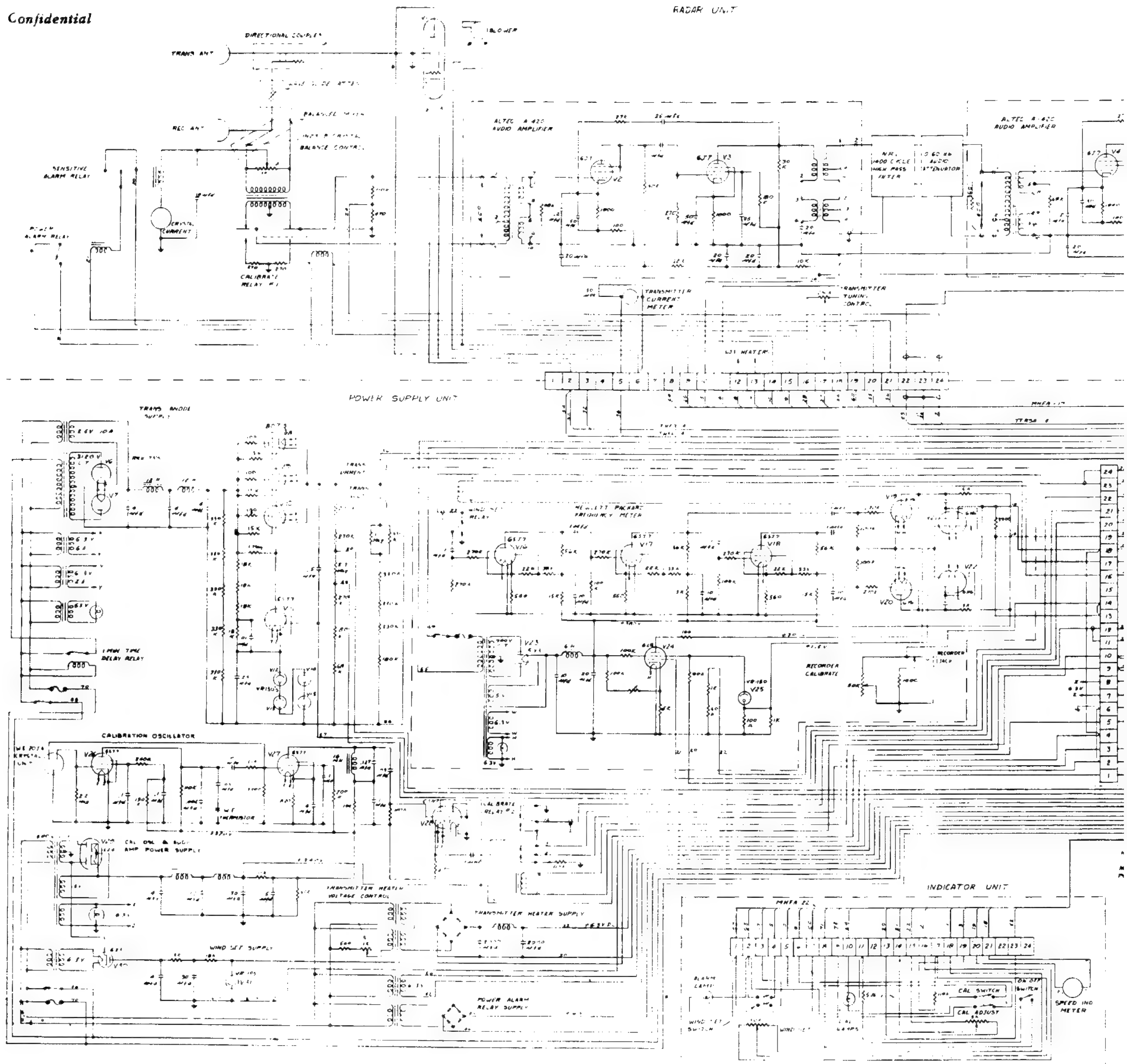
## Calibration Circuits

A crystal oscillator provides a calibrating signal which can be used to check the accuracy of the frequency measuring circuits. The oscillator stage, V26, operates at a frequency of 1.81818 kc and is controlled by the Western Electric 20JA crystal unit. The plate circuit of V27 is tuned to twice the crystal frequency so this stage functions as a frequency doubler. A cathode follower, V28, provides a low impedance output for the calibration oscillator.

For calibration, the calibrate knob on the indicator is depressed, closing the calibrate switch and engaging the calibration adjustment potentiometer. The calibrate switch energizes calibrate relays number 1 and 2. Calibrate relay number 2 removes the wind-set voltage from the speed indicating meter and connects the output of the calibration oscillator to the input transformer of the first audio amplifier, stage V2. At the same time, calibrate relay number 1 disconnects this input transformer from all other signals and places a 540-ohm termination, with the center point grounded, on the transformer. When the equipment is thoroughly warmed up, the calibration potentiometer should be adjusted so the pointer on the speed indicating meter is on the red line. Releasing the knob restores the relays to the normal operating position. The calibration potentiometer adjusts the grid voltage on the dc regulator tube V24.

## Wind-Set Circuits

The 6X5 rectifier, V30, together with the filter and gas regulator tube, V31, provide a negative voltage used for inserting a current into the speed-indicating meter proportional to


RADAR UNIT
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TRANS ANT
REC ANT
BALANCED MIXER
CRYSTAL BALANCE CONTROL
SENSITIVE ALARM RELAY
POWER ALARM RELAY
CRYSTAL CURRENT
CALIBRATE RELAY #1
ALTEC A 420 AUDIO AMPLIFIER
TRANSMITTER CURRENT METER
TRANSMITTER TUNING CONTROL
POWER SUPPLY UNIT
TRANS ANODE SUPPLY
HEWLETT PACKARD FREQUENCY METER
RECORDER CALIBRATE
CALIBRATION OSCILLATOR
CAL OSC & BUC AMP POWER SUPPLY
TRANSMITTER HEATER VOLTAGE CONTROL
TRANSMITTER HEATER SUPPLY
WIND SET SUPPLY
POWER ALARM RELAY SUPPLY
INDICATOR UNIT
CAL SWITCH
CAL ADJUST
SPEED IND METER
WIND SET SWITCH

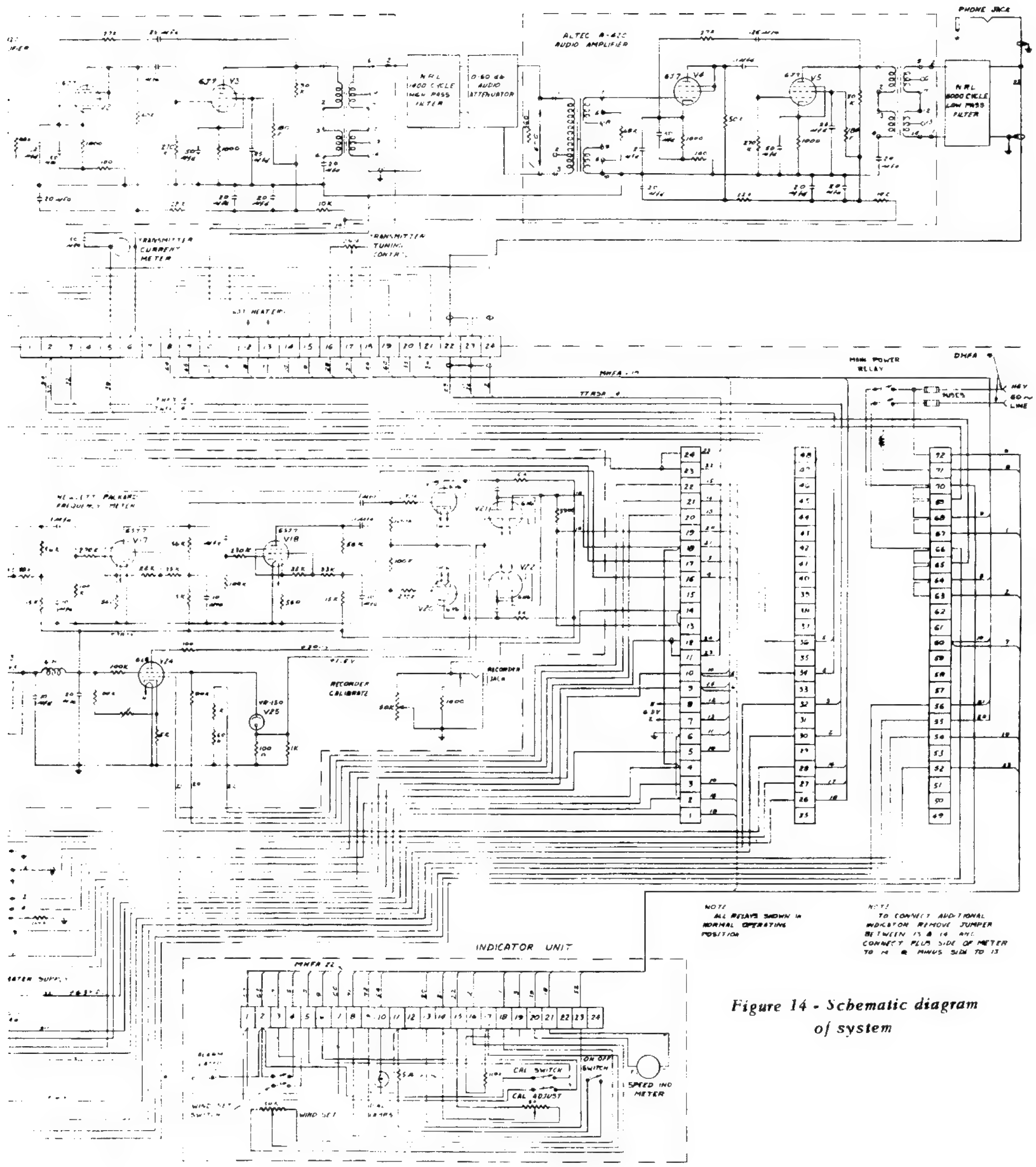


*Figure 14 - Schematic diagram of system*

the velocity of the wind across the deck. Then, when the echo from a landing airplane is received, the speed-indicating meter will register the air speed of the landing aircraft, which is the sum of the wind speed across the deck and the speed of the plane with respect to the carrier.

To set in proper wind speed, the wind-set knob on the indicator is depressed, closing the wind-set switch and engaging the wind-set potentiometer. The knob is then turned until the pointer on the speed-indicating meter is set to the wind speed. When the knob is released, the equipment will be ready to register the air speed of a landing aircraft. The wind setting need not be changed unless the wind speed across the deck changes.

When the wind-set knob is depressed, the wind-set switch closes and energizes the wind-set relay, which removes all signals from the frequency measuring circuits and grounds the input to the frequency meter while the wind speed is being adjusted.

## Alarm Circuits

An alarm lamp, provided on the indicator, will warn the operator when the system is not functioning properly.

The crystal current from the 1N23-B crystals in the balanced mixer flows through the coil of a sensitive alarm relay, designed to close the low-current contact at 0.2 ma and the high-current contact at 1.0 ma. If the crystal current is within this range, the alarm lamp will not light. Either high or low crystal current will close the sensitive alarm relay contacts, energizing the power alarm relay, which will then close the circuit to the alarm lamp.

## Power Supplies

Klystron Anode Supply - Tubes V6 through V15 comprise an electronically regulated anode power supply for the klystron transmitter tube with an output voltage adjustable between 1000 and 1500 volts negative. The voltage is adjusted by the anode voltage-control potentiometer located in the radar unit. This potentiometer adjusts the grid voltage of the 6SJ7 control tube V11.

Klystron Heater Supply - Two 6.3-volt transformers, with their secondaries connected in series, supply 12 volts to a dry-disc rectifier for the klystron heater supply. A 500-ohm fixed resistor and a 1000-ohm variable resistor in the primary circuit of one of the transformers are used to obtain the proper voltage. The output of the LC filter following the rectifier is 6.3 volts dc.

Calibration Oscillator and Audio Amplifier Power Supply - A conventional power supply using the 5Z4 rectifier, V29, on the calibration oscillator chassis, provides +220 volts for the calibration oscillator and +340 volts for the audio amplifiers. The 6.3-volt winding on the same transformer provides heater current for the calibration oscillator and the audio amplifiers.

Wind-Set Power Supply - The 6X5 rectifier, V30, together with the filter and gas regulator tube, V31, provides a 105-volt negative supply for wind set.

Frequency Meter Power Supply - Another supply, using the 5Y3 rectifier, V23, on the frequency meter chassis, provides +380 volts for the frequency meter stages.

Power-Alarm-Relay Power Supply - A Weston Rectiformer, consisting of a transformer and a dry-disc rectifier, provides 6 volts dc for the power-alarm-relay coil.

Tube List

| | |
|---|---|
| V-1 | X-23 klystron transmitter |
| V-2 | 6J7 audio amplifier |
| V-3 | 6J7 audio amplifier |
| V-4 | 6J7 audio amplifier |
| V-5 | 6J7 audio amplifier |
| V-6 | RKR-73 rectifier |
| V-7 | RKR-73 rectifier |
| V-8 | 807 regulator |
| V-9 | 807 regulator |
| V-10 | 807 regulator |
| V-11 | 6SJ7 voltage control |
| V-12 | VR-150 regulator |
| V-14 | VR-150 regulator |
| V-15 | VR-150 regulator |
| V-16 | 6SJ7 voltage amplifier |
| V-17 | 6SJ7 voltage amplifier |
| V-18 | 6SJ7 voltage amplifier |
| V-19 | 6V6 switching tube |
| V-20 | 6V6 switching tube |
| V-21 | 6H6 rectifier |
| V-22 | 6H6 rectifier |
| V-23 | 5Y3 rectifier |
| V-24 | 6L6 current regulator |
| V-25 | VR-150 regulator |
| V-26 | 6SJ7 calibration oscillator |
| V-27 | 6SJ7 frequency doubler |
| V-28 | 6SN7 cathode follower |
| V-29 | 5Z4 rectifier |
| V-30 | 6X5 rectifier |
| V-31 | VR-105 regulator |

## TUNING PROCEDURE

The radar consists of two antennas, one transmitting and one receiving, a klystron transmitter tube, a balanced waveguide mixer, two audio amplifiers, two audio filters, and a klystron power supply. All component parts except the power supply are located in the radar unit. The transmitter tube is an X-23 klystron, delivering approximately 5 watts of cw energy at 10,100 Mc to the transmitting antenna through a connecting waveguide. A portion of this energy is tapped off by a directional coupler and sent through a waveguide attenuator to a balanced mixer acting as the receiver. The other input to the balanced mixer is connected to the receiving antenna by a short waveguide run. The balanced mixer contains two 1N23B crystals connected to a repeat coil or transformer and includes a balancing potentiometer on the hinged panel.

In operation, the portion of the transmitted signal that is fed to the mixer acts as a local oscillator signal and causes between 0.2 and 1.0 ma of crystal current to flow as indicated on the crystal current meter. Energy reflected from a moving target enters the receiving antenna and mixes with the local oscillator signal in the balanced mixer, which produces a beat note with a frequency equal to the difference between the transmitted and received frequencies. This beat note or Doppler frequency will lie between 1400 and 5000 cycles, and is a direct measure of aircraft velocity.

The transmitter tuning control and the transmitter (klystron) anode current meter are located on the top panel inside the radar unit. On the second panel from the top are located a crystal current meter, a mixer balance control, and an audio attenuator.

Tuning the system is relatively simple:

(a) Be sure the klystron transmitter tube is securely mounted on the waveguide and that all connections are properly made. <u>These tubes are pre-tuned at the factory and no attempt should be made to adjust the eight tuning screws.</u>

(b) Adjust micrometer waveguide attenuator in back of panel to maximum attenuation. (Maximum reading on micrometer scale.)

(c) Test the 1N23B crystals on any crystal tester normally used for pulse radar crystals of 1N23 or 1N23B type. Replace crystals, if necessary.

(d) Swing panel to vertical position and adjust transmitter tuning control to counterclockwise position, and then adjust balance control to approximate center position.

(e) Make sure personnel are clear of circuits and place equipment in operation by closing the power switch on the indicator. The red alarm lamp will light since the r-f portion of the equipment is not yet operating properly.

(f) In approximately one minute, a time delay will apply voltage to the klystron, indicated by a reading on the plate-current meter in the radar unit. Adjust the transmitter tuning control clockwise until the plate-current meter reads approximately 100 ma. At this value of plate current (+ 15 ma), oscillation should occur as indicated by the crystal current meter. Adjust tuning control for maximum crystal current.

(g) Plug headphones into the jack provided and adjust balance control for minimum noise, or, if headphones are not available, adjust for minimum crystal current. Set the waveguide attenuator between 0.4 and 0.5 ma of crystal current and re-balance. In this adjustment, the audio attenuator should be set for minimum attenuation, i.e., fully clockwise.

(h) With zero wind set in, rotate the audio attenuator counterclockwise until the speed indicator meter at the landing signal officer's platform reads 15 knots. This residual reading is normal and caused by the thermal noise in the system actuating the counter circuits. The residual reading should not be reduced below 15 knots, as this will result in a reduction of system sensitivity. After checking the calibration, the equipment should be ready for operation.

## INSTALLATION ABOARD THE USS TARAWA

The approach-speed indicator was installed on the USS TARAWA for operational tests during the weeks of 16 and 23 April, 1951. The radar unit (Figure 15) was suspended beneath

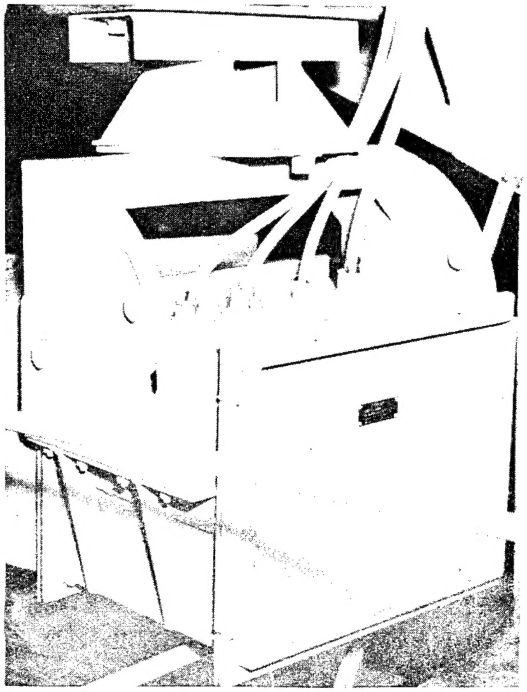

*Figure 15 - Antenna mounted under ramp of USS TARAWA*

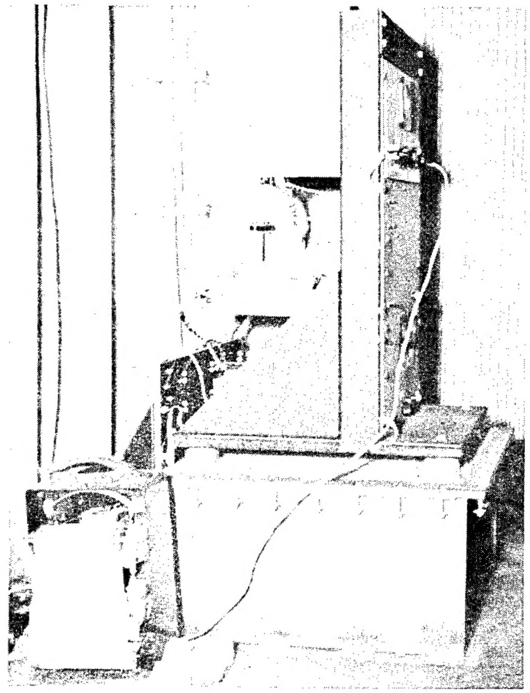

*Figure 16 - Power supply and E-A recorder*

the ramp on the starboard side of the carrier. A more central location would have been preferable, but would have entailed extensive catwalk construction to make the unit accessible. The power supply unit was mounted in a protected position below the flight deck as near the radar unit as possible (Figure 16). The indicator unit was mounted beside the anemometer aft of the landing signal officer's platform (Figure 17). An additional indicator, temporarily installed on the starboard catwalk approximately opposite the landing signal officer's position (Figure 18), was so located that motion pictures could be taken of the landing aircraft with the speed-indicating meter appearing in the lower left corner of the picture. The air speed of landing planes was registered on an Esterline-Angus recorder (Figure 16). During night operations, conventional aircraft were positively acquired in excess of 500 yards; in the daytime the cross-wind leg of the approach was made between 300 and 450 yards astern, considerably closer than had been expected. However, at all times the aircraft were acquired as soon as they entered the beam at a point $12^{\circ}$ to $14^{\circ}$ to port of a dead astern position. Jet aircraft, with their pronounced streamlining and consequent small radar cross section, were acquired from 250 to 350 yards astern. After calibrating the ship's anemometer, the speed indication was found to be within $\pm$ 1 or 2 knots of the speed as measured by the air-speed indicators in the various aircraft. No evidence of errors caused by propeller modulation or absence of a speed gate was found. After initial adjustments were made, no failures were noted during a weeks operation of the system.

During the tests the ship's anemometer was found to be somewhat unreliable, and since wind over the deck is added to the aircraft's closure rate with the carrier, the approaching aircraft's indicated air speed will be in error by an amount equal to the anemometer error. This error should be eliminated if accurate and reliable results are to be obtained.

An indication of the speed of jet aircraft was obtained for only six to six and one-half seconds, corresponding to a range of 250 to 350 yards. This was considered insufficient and

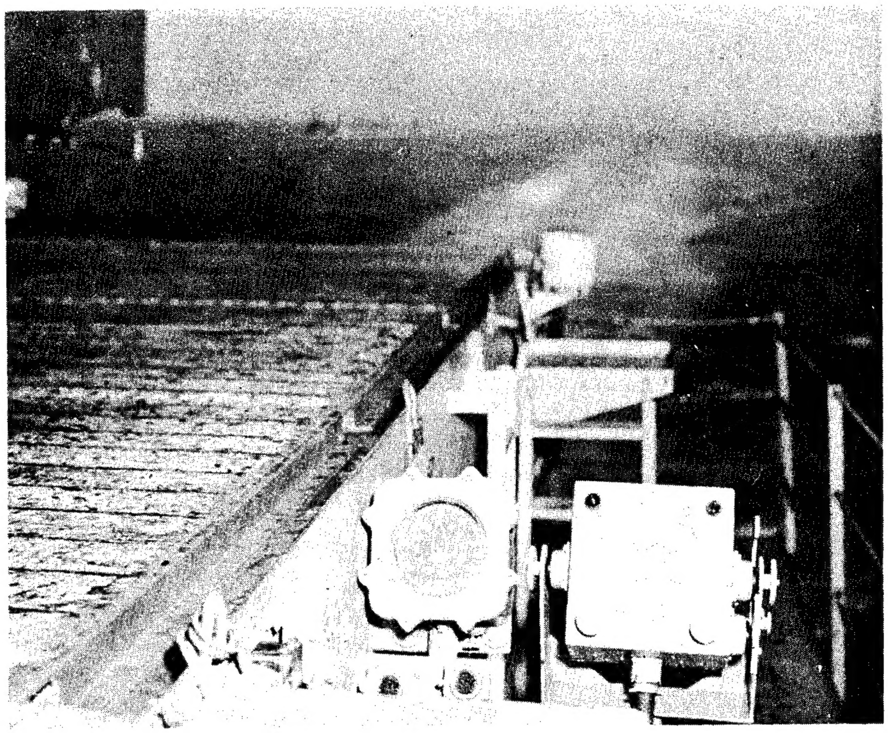

*Figure 17 - Indicator and anemometer on port catwalk. Picture taken from LSO's platform*

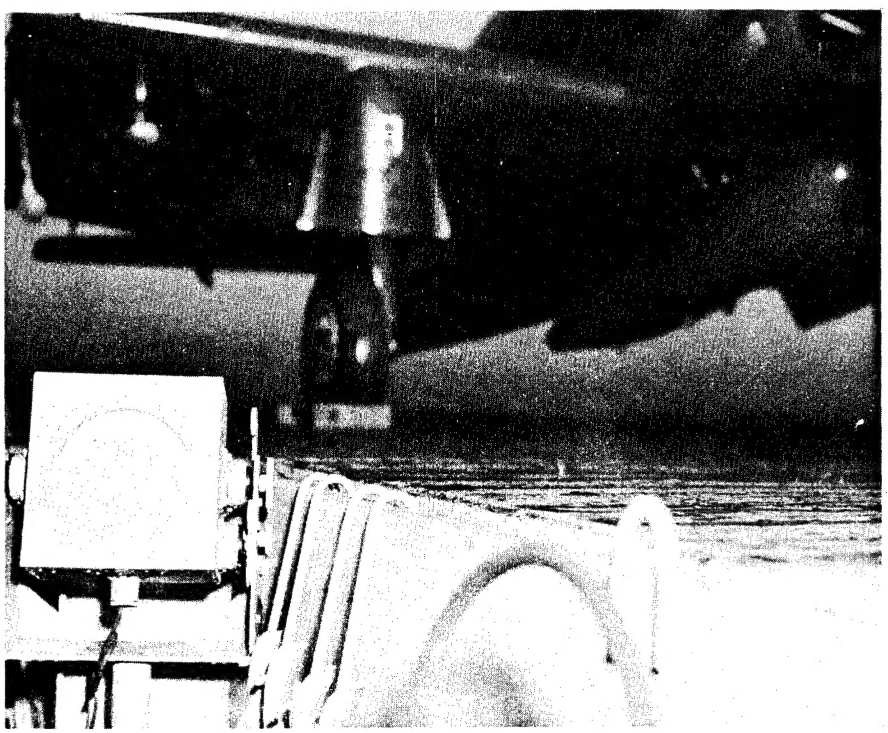

*Figure 18 - Auxiliary indicator on starboard catwalk*

in an effort to increase the radar cross section, the ship's crew installed a five-inch corner reflector on the nose wheel of a jet plane, but there was no improvement in range. This indicated that the radar cross section of the aircraft with landing gear down was considerably greater than the published information based on aircraft with landing gear up; it further indicated that the equipment had undergone a loss in sensitivity since its assembly in the Laboratory. The USS TARAWA was in drydock during the week of 3 June 1951, and the equipment was completely re-checked at that time. The klystron transmitter tube was delivering only 0.3 watt, and replacement was made with a tube that delivered a measured 8 watts. With the equipment restored to normal operation, acquisition of jet planes at the required 500 yards could be made.

Laboratory personnel accompanied the USS TARAWA during operations through the week of 10 June and observed ninety-nine jet landings (excluding wave-offs). The results on these landings are as follows: (a) average speed at cut 114.12 knots, (b) average wind across deck 37 knots, (c) average closing speed with the carrier 77.12 knots, (d) average time of reliable indication 12.1 seconds, (e) average range at which indication became reliable 525.36 yards. The extremes of time, a low value of 8 seconds and a high value of 16 seconds, were due to variation in the approach path of the particular aircraft. These landings were made in F2H and F9F aircraft by inexperienced pilots who were qualifying, and considerable variation in approach path was to be expected. The results of the tests indicate that the equipment operates according to the Bureau of Aeronautics specifications.

Personnel from the USS TARAWA will conduct an operational evaluation of the system; therefore, this report is not intended to be an expression of the ultimate usefulness of the equipment as an aid to the landing of aircraft on board a carrier.

## ACKNOWLEDGMENTS

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